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Effect of Silica Fume in Combination with Fly Ash on Mortar Properties

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Keywords
Portland cement, Fly ash, Silica fume, Binary, Ternary, Setting time, Mortar

Abstract

The influence of using silica fume in combination with fly ash on setting time of cement paste and mechanical properties of mortar have been investigated in this paper. Three groups named I, II, and III of mortar include sixteen mixes have been tested in this research work. Mortar specimens cured through keeping them in water until testing day. Initial and final setting times of cement paste were measured. The compression test carried out for mortar at different ages until 180 days, while the flexural strength of mortar measured at 28 days only. The results indicate that the use of silica fume in combination with fly ash as a ternary cementitious material increases the initial and final setting times and improves the measured mechanical properties of mortar. Such combinations offset the problems associated with using increased amounts of fly ash or silica fume required when these materials are used individually. The CO_2 emissions from the cement industry will be lowered due to the reduction of the cement content.

1. Introduction

Cement is considered as a main binder to produce mortar and concrete, and its production is associated with environmental problems. The main negative environmental impacts are greenhouse gases production and natural resources consumption [1-3]. Approximately 7% of CO2 in the atmosphere is produced due to cement industry only [4] and many attempts were done to develop new environmentally friendly construction materials. In addition, these new by-product materials provide the same performance to the cement [5]. Materials of natural origin such as industrial by-products or volcanic ash like slag and pulverized fuel ash, have been widely used as partial replacement of Portland cement in concrete. The advantages of uses these materials are improved technological properties, low cost, and

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reduction of waste accumulation [6]. Coal-burning power plants produce fly ash. Fly ash is widely used as a cementitious and a pozzolanic material in mortar and concrete. The properties of mortar and concrete improve because of using of fly ash in concrete [7].
The mechanical properties and the chemical durability of concrete can be improved using silica fume (micro-silica) as a pozzolanic admixture [8]. Chemical-resistant and/or economical high strength concrete can be produced by using of silica fume in various parts of the world [9]. However, Portland cement or fly ash is cheap as compared to silica fume.
The mechanical properties of the Portland cement mortar which is replaced by fly ash of Al Aslaah bricks factories in the south Iraq is evaluated [10]. Percent of 5% to 20% of fly ash are used as replacement ratio of cement. The initial and final setting time are increased with increasing the fly ash replacement percent. The mortar strengths were lowered than that of the standard cement mortar for all the fly ash percentages at early ages, while the 28 days' compressive strength was passed the standard cement mortar values for percentage 5% and 10% fly ash replacement [10]. A production of high strength concrete for practical application is indispensable of silica fume (SF) and fly ash (FA) individually or in combination. The fresh and hardened properties of concrete like cohesiveness, strength, permeability, and durability can be enhanced by using as certain percent of silica fume [11].
The comparison between the flow of mortar with ASTM Type I cement and ASTM Type I cement incorporating with 5% silica fume and 25% fly ash indicated no significant change [12]. The addition of silica fume in PC– SF– FA system cement is responsible of the slightly increase of early strength of system. The strength did not increase so much at and after 28 days [13]. The ternary cementitious blends of silica fume, fly ash and Portland cement have a significant advantage more than binary blends and even greater enhancements more than ordinary Portland cement [14]. Ternary blends of Portland cement, 5% silica fume and 10% to 20% fly ash with water reducing agent super plasticizer produce high strength mortar (HSM). The produced HSM can be used to rehabilitee reinforced concrete structures especially with ferrocement composites [15].
The main purpose of this paper is to study the setting time and the mechanical properties of the mortar of binary and ternary cementitious systems. Cement paste and mortar of binary and ternary cementitious systems of silica fume, fly ash and Portland cement, with various combinations investigated. The effect of the changing in the replacement percent of fly ash and silica fume on the properties of mortar with using local materials and high replacement percent were examined. The measured properties were included initial and final setting time of cement paste, flow of fresh mortar. Further, compressive, and flexural strength of hardened mortar determined.

2. Experimental Procedure

The used materials selected from locally sources in Egypt. The specific gravity of used cement and by-product materials are 3.16, 2.32, and 2.24 for ordinary Portland cement (OPC), fly ash (FA), and silica fume (SF), respectively. Moreover, the specific surface area of used OPC, FA, and SF are 3310, 3910, 153000 cm2/g, respectively. The properties of used sand are 2.63, 1.73 t/m3 and 2.69 for specific gravity, unit weight and fineness modulus, respectively. The chemical composition of OPC, FA and SF listed in Table 1.
The mix proportions of mortar summarize in Table 2. ASTM C 187-16 used to prepare the standard consistency of cement pastes. The measured properties of cement paste include water to cement ratio for standard consistency as well as initial and final setting time. The

measured properties of fresh and hardened mortar include flow, compressive strength, and flexural strength. The mixing of mortar has done according to the steps mentioned in ASTM C305-20. After casting, compaction made using mold vibrator. The test specimens de-molded after 24 hours. The samples put in water until time of testing.

Table1: Chemical composition of OPC, FA and SF

Chemical compound	OPC (%)	FA (%)	SF (%)
SiO2	19.49	55.0	97.30
AL2O3	7.36	25.0	0.46
Fe2O3	2.90	2.00	0.28
CaO	62.73	10.0	0.36
MgO	2.82	1.50	0.14
K2O	0.58	1.00	0.05
TiO2	---	2.00	---
SO3	2.4	---	0.10
Na2O	0.35	1.00	0.08
Loss on Ignition	1.37	2.50	1.23

Table 2: Mix proportions of mortar

Group No.	I						II					III				
Mix No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
System Type	Binary						Ternary					Ternary				
W/C ratio	0.4															
OPC (%)	100	90	80	70	60	50	95	85	75	65	55	90	80	70	60	40
FA (%)	---	10	20	30	40	50	---	10	20	30	40	---	10	20	30	40

3. Setting Time

The standard consistency of cement paste prepared after that initial and final setting times were measured. Water to cementitious materials ratios (w/cm) of paste for standard consistency represented in Figure 1. For group I of cementitious material paste, it noticed that w/cm ratios increase with increasing the percentage of fly ash. for group II and group III, w/cm ratio of paste increase with increasing the percentage of fly ash and silica fume. The maximum increase of water to cementitious materials ratios was recorded for Mix 16 with 27 % over the control Mix 1. This is due to the high carbonation content percent in fly ash, and this comply with the results of Krishna raj [16].

Figure 2 shows that the initial and final setting time of cementitious material paste. It is appearing from figure the initial and final setting time of cementitious material paste of group I increase with increasing the percentage of fly ash. The initial and final setting time was increased from 59 and 169 minutes to 140 and 260 minutes when the replacement ratio of cement by fly ash was changed from 0 to 50 percent. For group II, the initial and final setting time of cementitious material paste was increased from 80 and 190 minutes to 140 and 240 minutes when and the replacement ratio of cement by 5 percent of silica fume and fly ash was changed from 0 to 45 percent. For group III, the initial and final setting time of cementitious material paste was increased from 90 and 200 minutes to 144 and 244 minutes when the replacement ratio of cement by 10 percent of silica fume and fly ash was changed from 0 to 40 percent.

The initial setting time of Mix 16 (10 % SF & 40 % FA) is less than that of OPC mix. Moreover, the increase in the final setting time was recorded for Mix 6 (50% fly ash) and

Mix 16 (10 % SF & 40 % fly ash) as 54 % and 44 % over the control Mix 1. The increase in setting time for cement paste with fly ash or with SF and FA as cementing materials is the result of increasing water to cementitious materials ratio and decreasing cement content this comply with the results of Ali [10] and Sri Ravindra rah [17].

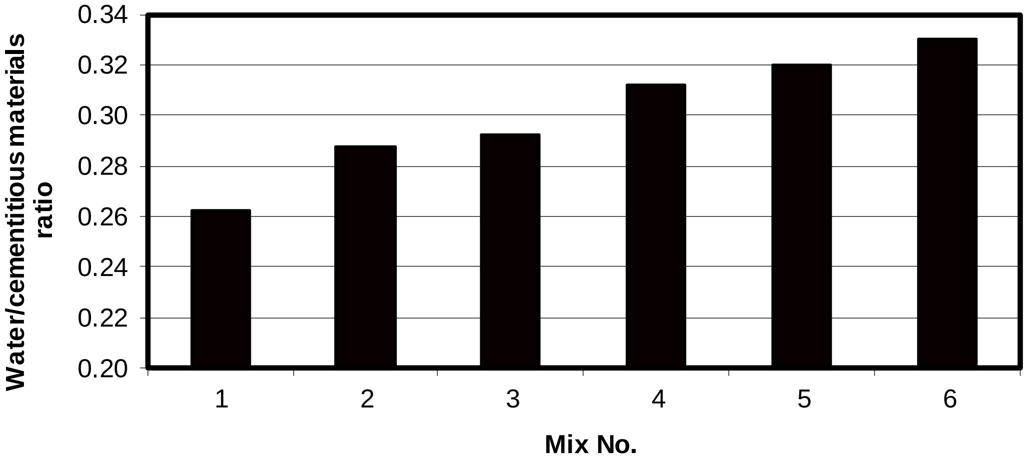

Figure 1-a: Water / cementitious materials ratio of paste of Group I

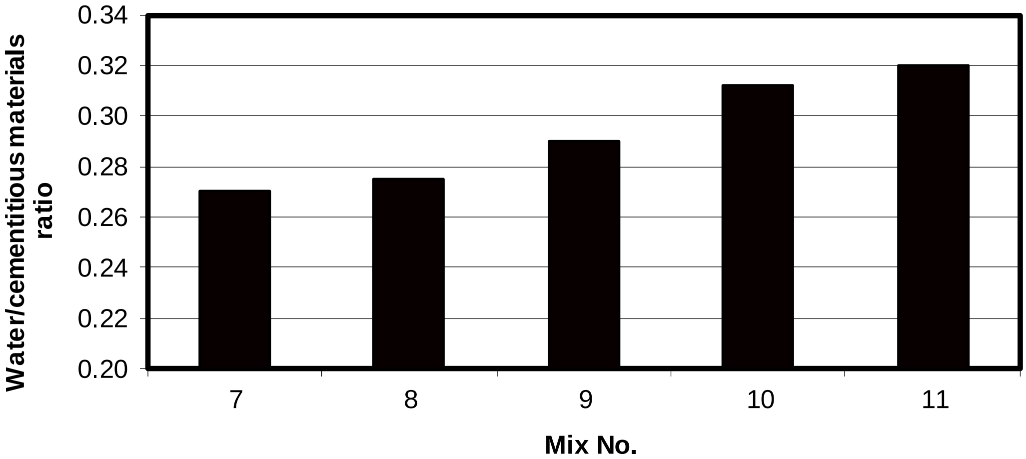

Figure 1-b: Water/ cementitious materials ratio of paste of Group II

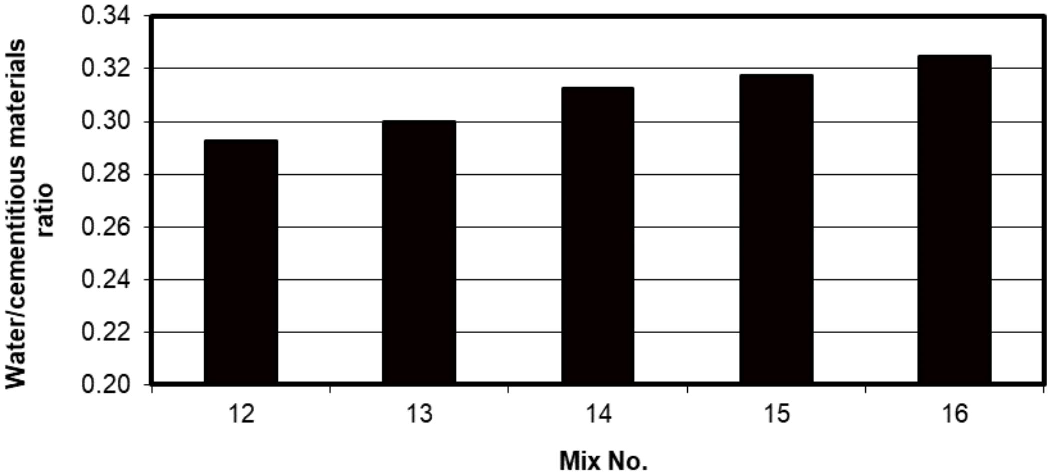

Figure 1-c: Water / Cementitious Materials Ratio of Paste of Group III

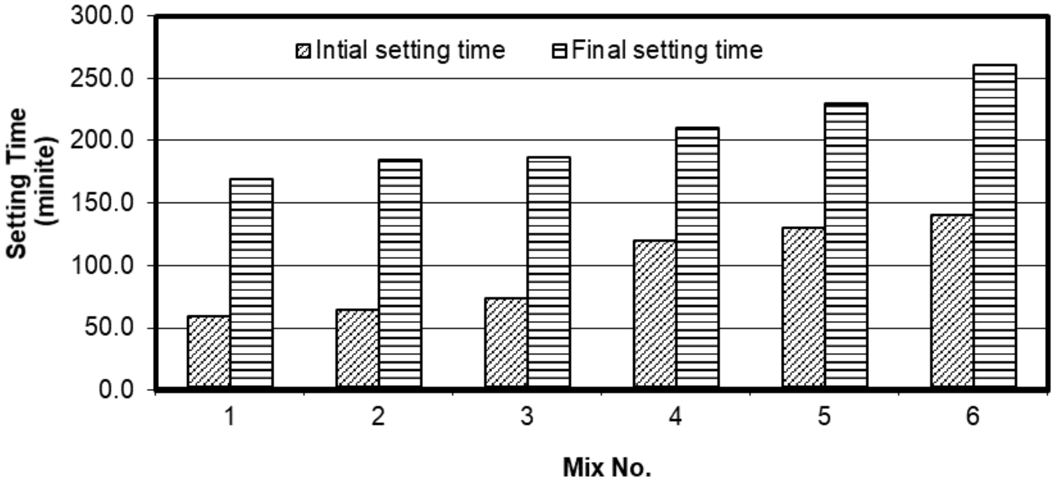

Figure 2-a: Setting times of paste of Group I

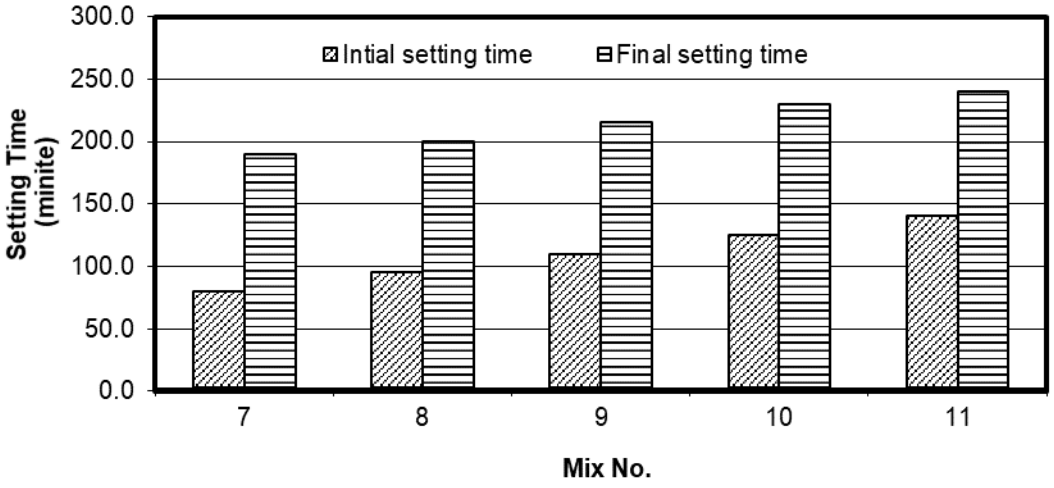

Figure 2-b: Setting Times of Paste of Group II

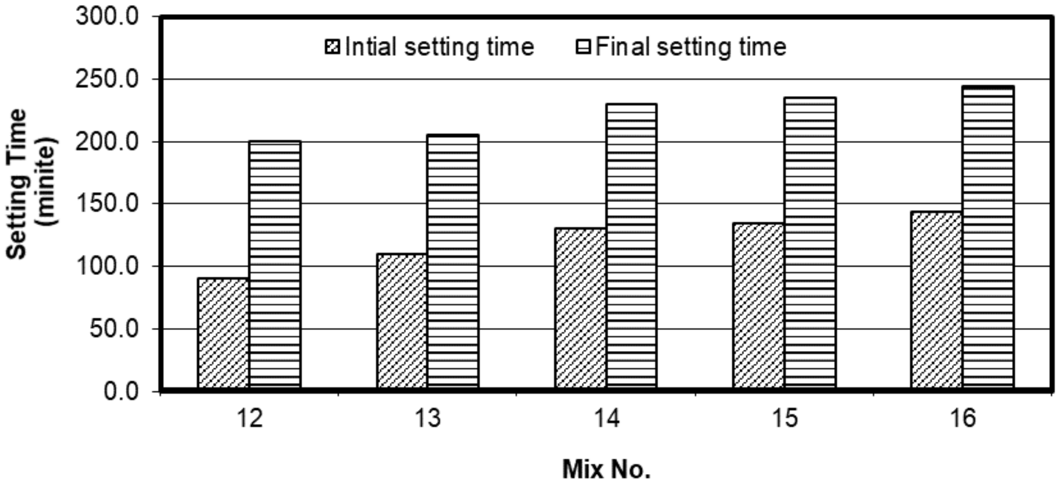

Figure 2-c: Setting Times of Paste of Group III

4. Properties of Fresh Mortar

The measured flow values of fresh mortar mixture are shown in Figure 3. The flow of fresh mortar mixture reduced gradually with increasing of fly ash percent as shown in Figure 3-a.

The maximum flow was obtained 60 % for control mortar (mix 1) among all mixture. In contrast, mix No 15 provided the lowest flow of 9%. Figure 3-b and 3-c show that the ternary cementitious system of fly ash and silica fume reduces the flow of fresh mortar. This is due to fly ash and silica fume need high amount of water more than OPC. This is due to very high surface area of silica fume.

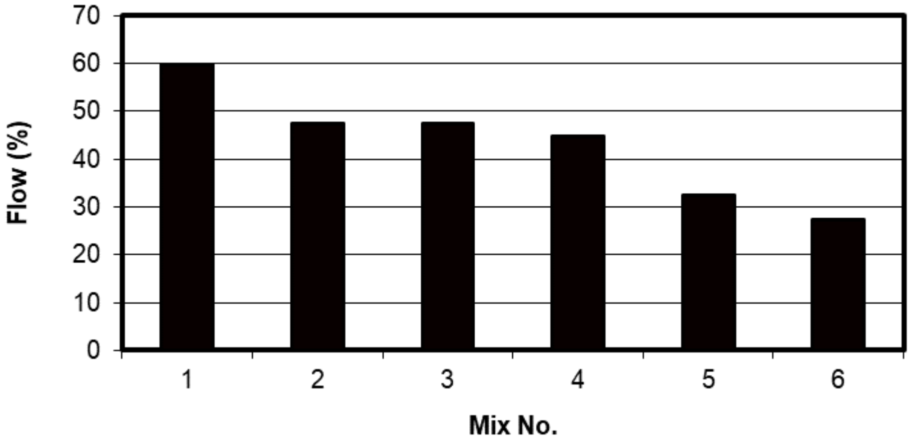

Figure 3-a: Flow of mortar of Group I

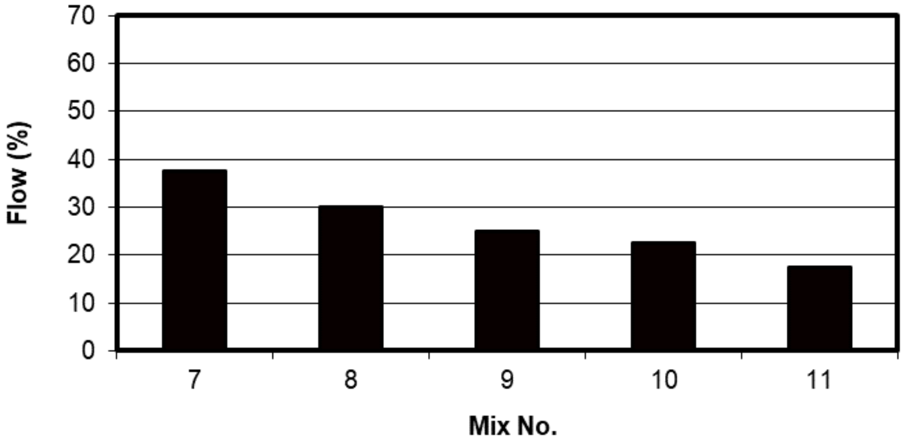

Figure 3-b: Flow of mortar of Group II

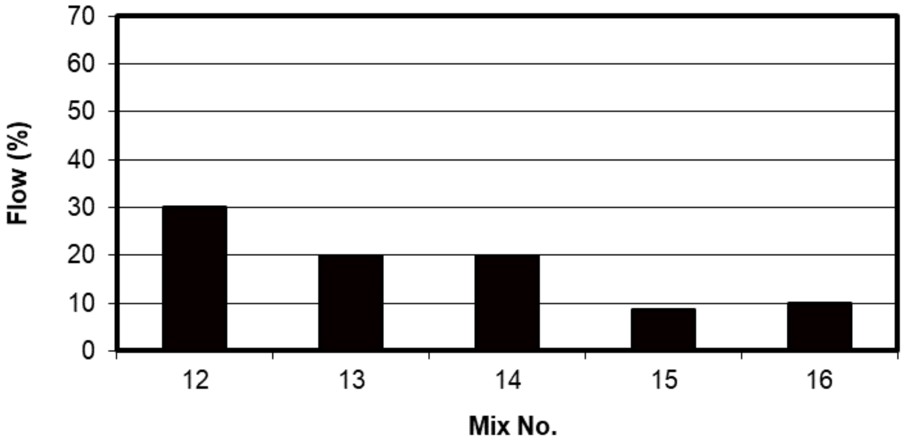

Figure 3-c: Flow of mortar of Group III

5. Properties of Hardened Mortar

Figures 4, 5 and 6 show the compressive strength of tested mortar up to age of 180 days, the test carried out according to ASTM C109-16. For group I mortar mixtures with fly ash show lower compressive strength values at ages 3 and 7 days while the results at ages 28, 90 and 180 days of fly ash (10% to 30%) are greater or equivalent compressive strength than those of the corresponding mortar mix made with OPC. At 90 days, mortar with 10 %, 20 % and 30% fly ash replacement showed improvement in the compressive strength of 17%, 1% and 1 % over the control mortar, respectively, while their 180 days, compressive strength is 30%, 25% and 25 % over the control mortar, respectively. The obtained results are complied with previous studies [18].

For mortar mixes of groups II, the results of mortar mixtures of silica fume (5%) in combination with fly ash (10% to 30%) are equivalent or lower than compressive strength values at early ages until 28 days after that are greater than compressive strength of the corresponding mixtures made with OPC. The mortar mixtures with 5 % SF in combination with 10 %, 20 and 30% fly ash replacement have 180 days' compressive strength values that are 25%, 20% and 10 % higher than that of the control mortar, respectively. For mortar mixes of groups III, the results of mortar mixtures of silica fume (10%) in combination with fly ash (10% to 30%) are equivalent or lower than compressive strength values at early ages until 28 days after that are greater than compressive strength of the corresponding mixtures made with OPC. At 180 days, mortar with 10 % SF in combination with 10 %, 20 and 30% fly ash replacement showed improvement in the compressive strength of 38%, 20% and 10 % over the control mortar.

The mortar mixtures with 5 % SF and 10% SF have 7 days' compressive strength values that are 12% and 17 % higher than that of the control mortar, respectively. While their 180 days, compressive strength is 25% and 30 % over the control mortar, respectively. The obtained data show that the increase content of silica fume in the binary cementitious system of OPC and silica fume increases the mortar compressive strength at its all age. The most reason for this is the content of amorphous of silica and large surface area of SF leads to good pozzolanic reaction [19]. Moreover, the pore spaces in the cement paste filled by silica fume particles act as fillers thus making the matrix denser [20, 21].

The combination of silica fume, fly Ash and ordinary Portland cement in a ternary cement system should result in several synergistic effects, Silica fume compensates for low early strength of mortar with fly ash. While Fly ash increases long-term strength development of silica fume mortar as shown in Figure 6. Moreover, the relatively low cost of fly ash offsets the high cost of silica fume.

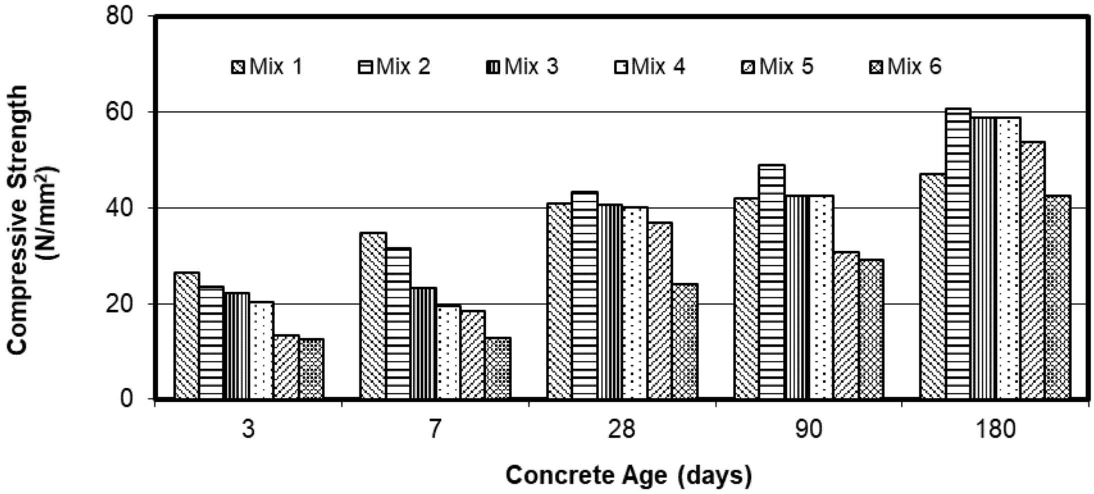

Figure 4-a: Compressive strength of Group I

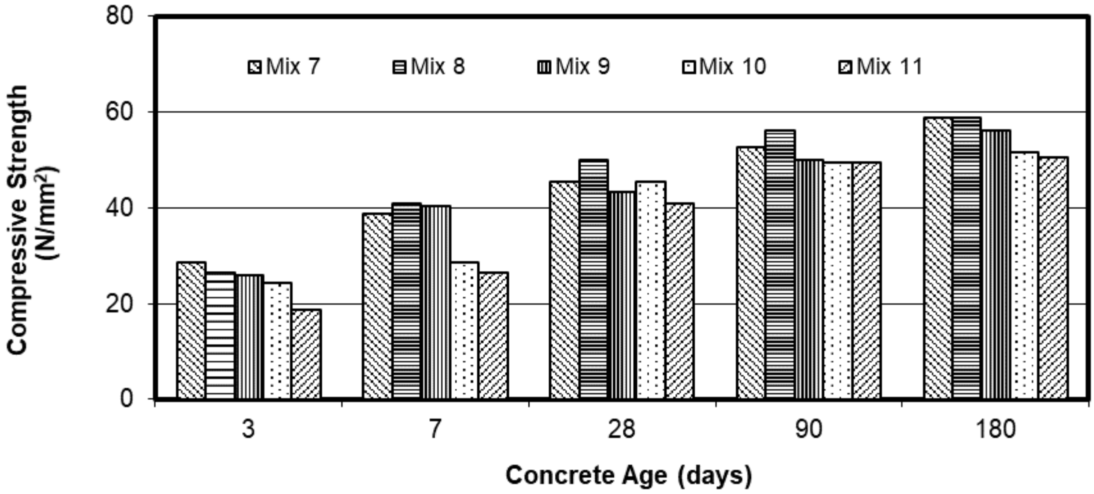

Figure 4-b: Compressive strength of Group II

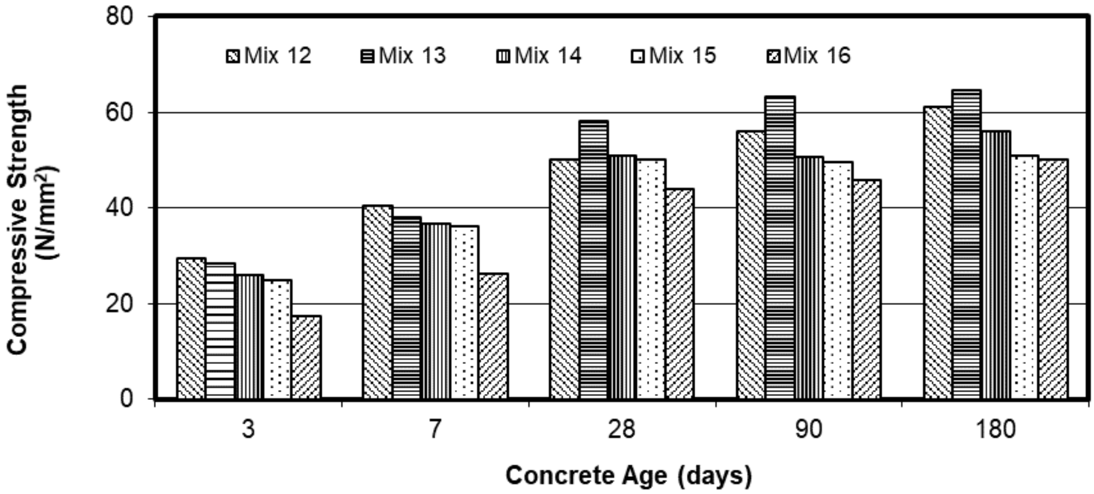

Figure 4-c: Compressive strength of Group III

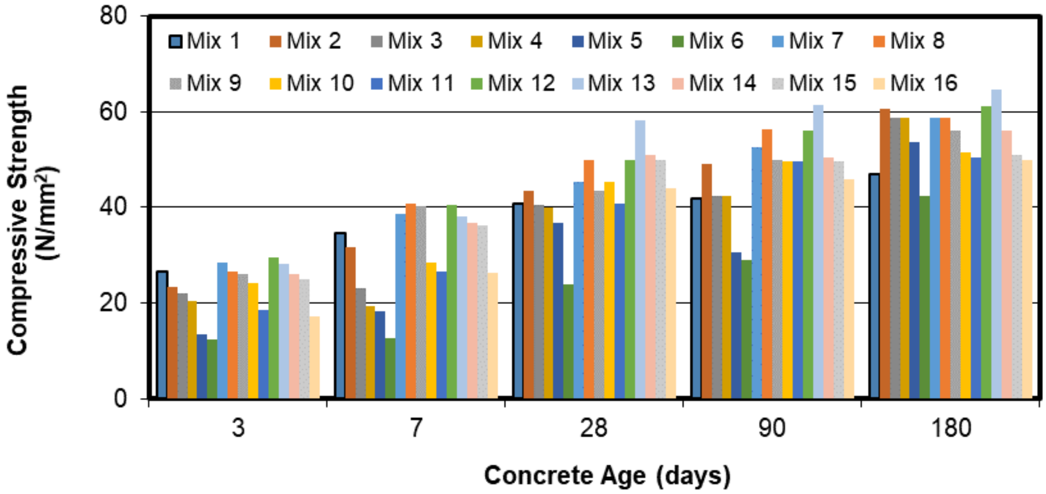

Figure 5: Compressive strength of All Groups

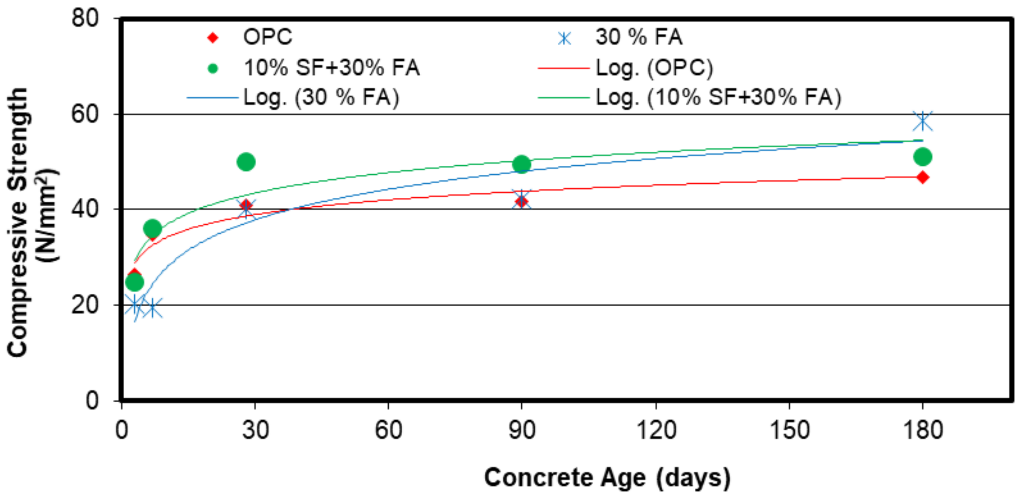

Figure 6: Compressive strength of Selected Mixes

Figure 7 shows the measured flexural strength of mortar at 28 days, the test carried out according to ASTM C 348-20. The results of the fly ash mortar of group I showed flexural strength lower than those of OPC. Moreover, the results of the flexural strength decreased with increasing the replacement ratio of fly ash. The result of group II mortar mixes with 10% fly ash in combination with 5% silica fume showed flexural strength more than those of OPC (control mix) and binary mix of OPC with 5 % silica fume. The percentage of increase in flexural strength of mortar mixes with 10% fly ash in combination with 5 % silica fume was 11.0% over the control mortar. The result of group III mortar mixes with fly ash (10% to 20%) in combination with 10 % silica fume showed flexural strength more than those of OPC and binary of OPC with 10 % silica fume. The flexural strength of mortar mixes with 10% and 20% fly ash in combination with 10 % silica fume were higher than the control mortar by 25 % and 22 % respectively, while the mortar mixture with 30% fly ash in combination with 10 % silica fume is lower than that the control mortar by 6 %.

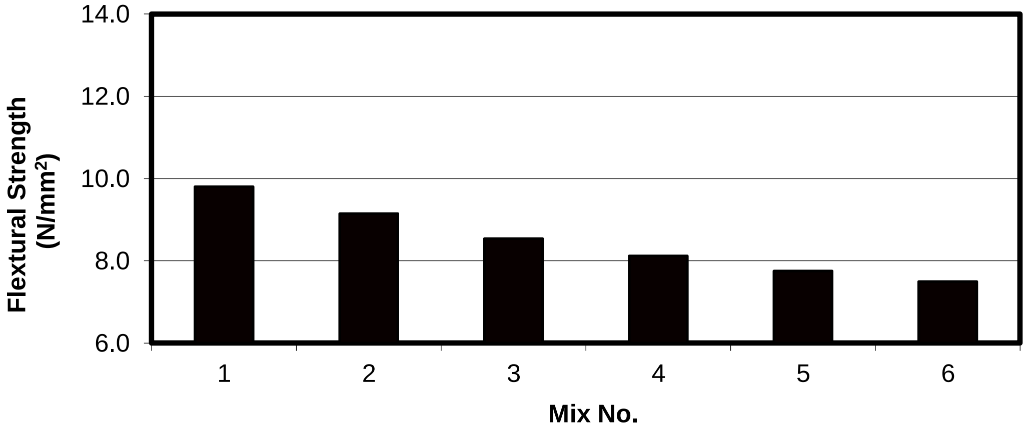

Figure 7-a: Flexural Strength of Mortar of Group I

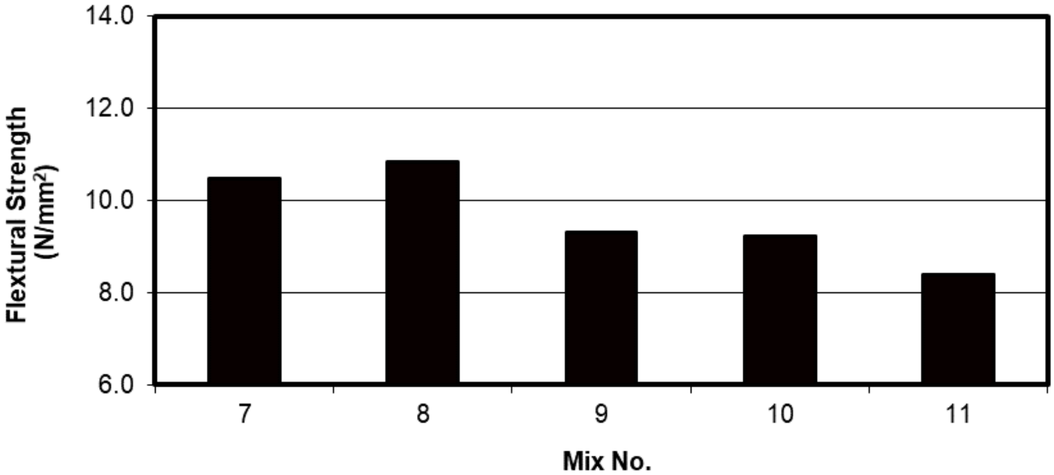

Figure 7-b: Flexural Strength of Mortar of Group II

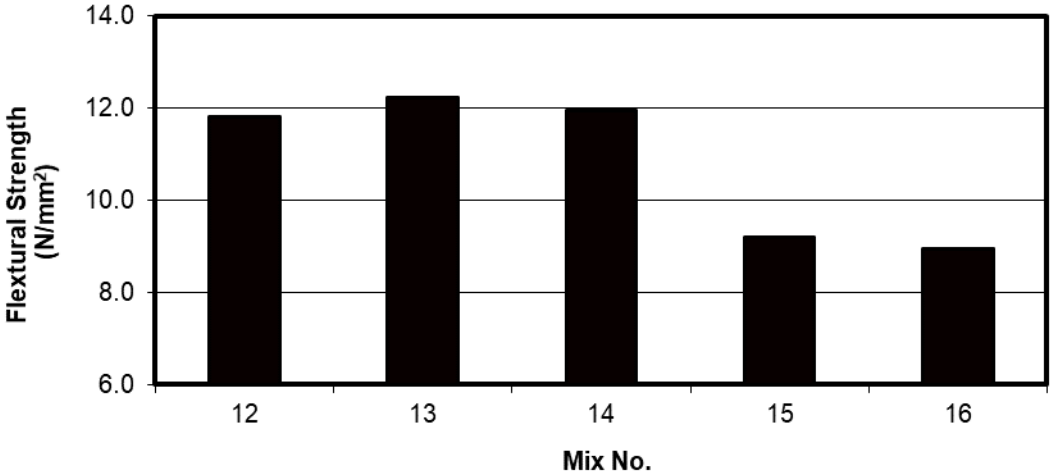

Figure 7-c: Flexural Strength of Mortar of Group III

6. Conclusions

1. Silica fume in combination with fly ash as a replacement ratio of cement is a retarder additive that increases initial and final setting time.
2. Mortar flow of silica fume with fly ash decreasing with increasing the percent of used cementitious materials.
3. Combination of fly ash (10% to 30%) with silica fume (5% to 10%) show compressive strength more than in those of OPC after 28 days.
4. Flexural strength of silica fume (10%) mortar with fly ash (10% to 30%) are greater than OPC mortar at 28 days.
5. Combinations of silica fume (5% to 10%) with fly ash (10% to 30%) show satisfactory performance in hardened mortar. Such combinations produce mortar with generally excellent properties and offset the problems associated with using the increased amounts of fly ash or silica fume required when these materials are used individually.
6. The CO2 emissions from the cement industry will be lower due to reduce the content of cement by 60% resulted in improved the cement mortars compressive strength.

References

[1] Karim M, Zain M, Jamil M, and Lai F, "Fabrication of a non-cement binder using slag, palm oil fuel ash and rice husk ash with sodium hydroxide". Construction and Building Materials, vol. 49, pp. 894-902, 2013.

[2] Shubbar A, Jafer H M, Dulaimi A, Atherton W, and Al-Rifaie A, "The Development of a Low Carbon Cementitious Material Produced from Cement, Ground Granulated Blast Furnace Slag and High Calcium Fly Ash". International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, vol. 11, no. 7, pp. 905-908, 2017.

[3] Shubbar A, Sadique M, Kot P, and Atherton W, "Future of clay-based construction materials – A review". Construction and Building Materials, vol. 210, pp. 172-187, 2019.

[4] Shubbar A, Jafer H, Dulaimi A, Hashim K, Atherton W, and Sadique M, "The development of a low carbon binder produced from the ternary blending of cement, ground granulated blast furnace slag and high calcium fly ash: An experimental and statistical approach". Construction and Building Materials, vol. 187, pp. 1051-1060, 2018.

[5] Aprianti E, Shafigh P, Bahri S, and. Farahani J N, "Supplementary cementitious materials origin from agricultural wastes – A review". Construction and Building Materials, vol. 74, pp. 176-187, 2015.

[6] Escalante-Garcia, J.-I., Sharp, J.H "The chemical composition and microstructure of hydration products in blended cements ", Cement & Concrete Composites, 26 (8), 967–976, 2004.

[7] Chai J., Kraiwood K., Vanchai S., Theerarach L. " Use of ground coarse fly ash as a replacement of condensed silica fume in producing highs-strength concrete", Cement and Concrete Research, 34 (4), 549–555, 2004.

[8] David B. McDonald, A. S. AI-Gahtani, Rasheeduzzafar, A. A. AI-Mussallam, Yacoub M. Najjar, and Imad A. Basbeer. ―Discussion of Resistance of Silica-Fume Concrete to Corrosion-Related Damages.‖ ASCE Mat. J (8), pp. 177-178, 1996.

[9] Safwan A. Khedr, and Mohamed NagibAbou-Zeid "Characteristics of Silica Fume Concrete", ASCE Mat. J (6), pp. 357-375,1994.

[10] Aly A. K., Fadhil K. I. and Kadhim Z. N. "Effect the Local Fly Ash on Cement Mortar Properties", Journal of University of Babylon, Engineering Sciences, Vol. (26), No. (5), 2018.

[11] Lakhbir S., Arjun K. and Anil S. "Study of Partial Replacement of Cement by Silica Fume", International Journal of Advanced Research, Volume 4, Issue 7, 104-120, 2016.

[12] Thomas, M.D.A., Shehata, M.H., Shashiprakash, S.G., Hopkins, D.S., Cail, K., "Use of Ternary Cementitious Systems Containing Silica Fume and Fly ash in Concrete", Cement and Concrete Research, Vol. 29, No. 8, pp. 1207 – 1214, 1999.

[13] Lane, D.S., Ozyildirim, C., "Combinations of Pozzolans and Ground, Granulated, Blast Furnace Slag for Durable Hydraulic Cement Concrete", Final Report, Virginia Department of Transportation, University of Virginia, Charlottesville, Virginia, VTRC 00-R1, Aug. 1999.

[14] Hariharan, A.R., Santhi, A.S. and Mohan Ganesh, G. "Effect of ternary cementitious system on compressive strength and resistance to chloride ion penetration". International Journal of Civil and Structural Engineering (4), 2011.

[15] Sasiekalaa K. and Malathy R. "Behavior of Mortar Containing Silica fume and Fly ash used for Ferrocement laminates" Jr. of Industrial Pollution Control 28 (1), pp 13-20, 2012.

[16] Krishnaraj L. and Ravichandran P.T. "Characterisation of ultra-fine fly ash as sustainable cementitious material for masonry construction" Ain Shams Engineering Journal No. 12, pp 259 – 269, 2021.

[17] Sri Ravindrarajah R. and Tam C. T. "Properties of Concrete Containing Low-Calcium Fly Ash Under Hot and Humid Climate" Third International Conference, Trondheim, Norway pp 139-155, 1989.

[18] Antoni, Lucky Chandra and Djwantoro Hardjito "The impact of using fly ash, silica fume and calcium carbonate on the workability and compressive strength of mortar" The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5), pp 773-779, 2015.

[19] Malhotra V.M. and Mehta P.K., "Pozzolanic and Cementitious Materials, Advance in Concrete Technology" Vol.1, Gordon, and Breach Publishers, 1996.

[20] Yazici H., Yardimci M.Y., Aydin S. and Karabulut A.S. "Mechanical properties of reactive powder concrete containing mineral admixtures under different curing regimes" Constr. Build. Mater., 23, pp 1223-1231, 2009.

[21] Elahi A., Basheer P.A.M., Nanukuttan S.V. and Khan Q.U.Z., "Mechanical and durability properties of high-performance concretes containing supplementary cementitious materials" Constr. Build. Mater., 24, pp 292-299, 2010

تأثير استخدام السيليكافيوم والرماد المتطاير معاً على خواص المونة

الملخص العربى

يتناول هذا البحث دراسة تأثير استخدام السيليكافيوم والرماد المتطاير معاً على زمني الشك الابتدائي والنهائي لعجينة الاسمنت والخواص الميكانيكية للمونة. حيث تم دراسة ثلاث مجموعات من خلطات المونة بإجمالي ١٦ خلطة مع معالجة العينات بالمياه حتى يوم الاختبار. وقد تم اجراء اختبار الضغط لعينات المونة عند الاعمار المختلفة للعينات حتى عمر ١٨٠ يوم بينما تم اجراء اختبار الإنحناء عند عمر ٢٨ يوم. وقد أظهرت النتائج أن استخدام السيليكافيوم والرماد المتطاير معاً كمادة اسمنتية ثلاثية مع الاسمنت البورتلاندي العادي يزيد من زمني الشك الابتدائي والنهائي للعجينة الاسمنتية وتحسن الخواص الميكانيكية المقاسة لعينات المونة. كما تبين من النتائج ان استخدام السيليكافيوم والرماد المتطاير معاً كمادة اسمنتية ثلاثية مع الاسمنت البورتلاندي العادي يؤدي الي تقليل السلبيات المرتبطة باستخدام كل منهما منفرداً وزيادة الايجابيات على الخواص المختلفة للمونة التي تم تناولها في هذه الدراسة. كما ان زيادة استخدام هذه المواد الاسمنتية في صناعة الخرسانة يؤدي الي تقليل كمية الاسمنت المطلوبة لصناعة الخرسانة على المستوي العالمي وبالتالي انخفاض كمية ثاني أكسيد الكربون المنبعثة من صناعة الاسمنت.